Surveys of Reservoir Sites

Letter

from

The Secretary of the Interior

Transmitting

In Response to Resolution of the Senate of February 7, 1899, Report from the Director of the United States Geological Survey Relative to Reservoir Sites, with Brief Memoranda as to Present Conditions of Water Storage, etc.

February 13, 1899 – Referred to the Committee on the Geological Survey and Ordered to be Printed.

55th Congress
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LETTER

FROM

THE SECRETARY OF THE INTERIOR,

TRANSMITTING,

IN RESPONSE TO RESOLUTION OF THE SENATE OF FEBRUARY 7, 1899, REPORT FROM THE DIRECTOR OF THE UNITED STATES GEOLOGICAL SURVEY RELATIVE TO RESERVOIR SITES, WITH BRIEF MEMORANDA AS TO PRESENT CONDITIONS OF WATER STORAGE, ETC.

FEBRUARY 13, 1899.—Referred to the Committee on the Geological Survey and ordered to be printed.

DEPARTMENT OF THE INTERIOR,
Washington, February 11, 1899.

SIR: Under date of the 7th instant the Senate passed the following resolution:

Resolved, That the Secretary of the Interior be, and hereby is, directed to furnish in concise form for the use of the Senate a general statement of the origin, character, and extent of the surveys of reservoir sites made by the United States Geological Survey, with brief memoranda as to present conditions of water storage and the more important sites in each large hydrographic basin, also a summary of estimates as to probable cost of constructing suitable dams at points where the stored water will be of most immediate value to the public.

In reply thereto I have the honor to hand you herewith copy of a report from the Director of the Geological Survey, which embodies the information called for by said resolution.

Very respectfully,

C. N. BLISS,
Secretary.

The PRESIDENT OF THE SENATE.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., February 11, 1899.

SIR: I have the honor to acknowledge, by reference from you dated February 10, the following resolution:

Resolved, That the Secretary of the Interior be, and hereby is, directed to furnish in concise form for the use of the Senate a general statement of the origin, character,

and extent of the surveys of reservoir sites made by the United States Geological Survey, with brief memoranda as to present conditions of water storage and the more important sites in each large hydrographic basin, also a summary of estimates as to probable cost of constructing suitable dams at points where the stored water will be of most immediate value to the public.

In accordance with this resolution, I beg to submit herewith in duplicate a report upon reservoir surveys, prepared by Mr. F. H. Newell, hydrographer.

I have the honor to be, your obedient servant,

CHAS. D. WALCOTT,
Director.

The SECRETARY OF THE INTERIOR.

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SURVEYS OF RESERVOIR SITES.

By F. H. NEWELL.

ORIGIN OF SURVEYS.

The origin of the reservoir investigations carried on by the Geological Survey may be traced to the early work, and particularly the report prepared by Maj. J. W. Powell on the Lands of the Arid Region, transmitted April 1, 1878. On page 12 of that report he calls attention to the increase of irrigable area possible by flood storage, and notes that there are two methods of conserving the waste water: First, in the upper valleys among mountains and foothills; and, second, in ponds within or adjacent to farms where irrigation is being carried on. At that time reservoir sites of both these classes were practically untouched, but since then many of the smaller sites adjacent to cultivated lands have been put to use in whole or in part. At the present time the public is concerned mainly with the larger and more expensive storage projects relating to the upper catchment areas of the streams.

Major Powell's early report, while discussing conditions throughout the arid West, brought out details particularly concerning Utah. He showed, for example, that at the sources of the Sevier River reservoirs could be constructed in the broad basins drained by narrow gorges cut through volcanic sheets. He pointed out particularly Panguitch Lake, which lies in a broad basin 15 miles southwest of the town of the same name. By throwing a dam 30 feet high and 50 or 60 feet long across the outlet a lake would be formed with an area of 6 or 7 square miles. Other reservoirs could be formed by dams across the upper part of East Fork Canyon, also in Grass Valley, upon Fish Lake plateau, upon the Sevier plateau, and in the valleys drained by Salina Creek and its tributaries. Sevier River itself can be cheaply dammed at several gorges, notably at the head of Marysvale Canyon. Since the time of the publication of this report several of these reservoirs have been built, while others now needed are waiting for necessary funds. It was not until ten years after the publication of this report—namely, in 1888—that Congress took definite action in authorizing reservoir surveys.

Shortly after the publication of the report on the Lands of the Arid Region, by Major Powell, the Survey, of which he was the head, was abolished, with other similar organizations, and in place of these the present United States Geological Survey was created. This present Survey is concerned with the water resources of the country primarily through what is known as the organic law contained in the act of

Congress of March 3, 1879. To the paragraph creating the office of Director of the Geological Survey the following proviso was attached:

> * * * That this officer shall have the direction of the Geological Survey and the classification of the public lands and examination of the geological structure, mineral resources, and products of the national domain, and that the Director and members of the Geological Survey shall have no personal or private interests in the lands or mineral wealth of the region under survey, and shall execute no surveys or examinations for private parties or corporations. (Approved March 3, 1879. Stat. L., vol. 20, p. 394.)

The first requisite in the "classification of the public lands and the examination of the geological structure, mineral resources, and products of the national domain," is a topographic map for guidance and for exhibiting the results. Since the organization of the Survey, therefore, a large part of its energies has been concentrated on the preparation of such a map, showing all elevations by means of contours, also the location of streams, towns, roads, railroads, and canals for irrigation or transportation, isolated houses, and boundaries of States, counties, and towns. This map exhibits the drainage area of streams, the relative elevations of catchment basins and irrigable lands, the topographic features favorable to water conservation, the land-office lines, the slopes of valleys, and many other details of importance to the development of water powers and of irrigation or the reclamation of the arid lands.

In 1887 the Director of the Geological Survey was called upon by Congress to consider the question of Federal recognition of the irrigation subject. A resolution was passed requiring the Secretary of the Interior, by means of the Director of the Geological Survey, to make an investigation of that portion of the arid region of the United States where agriculture is carried on by means of irrigation. The resolution reads as follows:

> Whereas a large portion of the unoccupied public lands of the United States is located within what is known as the arid region, and now utilized only for grazing purposes, but much of which, by means of irrigation, may be rendered as fertile and productive as any land in the world, capable of supporting a large population, thereby adding to the national wealth and prosperity;
>
> Whereas all the water flowing during the summer months in many of the streams of the Rocky Mountains, upon which chiefly the husbandman of the plains and the mountain valleys chiefly depends for moisture for his crops, has been appropriated and is used for the irrigation of lands contiguous thereto, whereby a comparatively small area has been reclaimed; and
>
> Whereas there are many natural depressions near the sources and along the courses of these streams which may be converted into reservoirs for the storage of the surplus water which during the winter and spring seasons flows through the streams; from which reservoirs the water there stored can be drawn and conducted through properly constructed canals, at the proper season, thus bringing large areas of land into cultivation and making desirable much of the public land for which there is now no demand: Therefore, be it
>
> *Resolved by the Senate and House of Representatives of the United States of America in Congress assembled*, That the Secretary of the Interior, by means of the Director of the Geological Survey, be, and he is hereby, directed to make an examination of that portion of the arid regions of the United States where agriculture is carried on by means of irrigation, as to the natural advantages for the storage of water for irrigating purposes, with the practicability of constructing reservoirs, together with the capacity of the streams and the cost of construction and capacity of reservoirs, and such other facts as bear on the question of storage of water for irrigating purposes; and that he be further directed to report to Congress as soon as practicable the result of such investigation. (Approved March 20, 1888. Stat. L., vol. 25, pp. 618, 619.)

This was followed by the passage of an act containing an appropriation of $100,000 for the purpose of investigating the extent to which

the arid region of the United States can be redeemed by irrigation. This act is as follows:

For the purpose of investigating the extent to which the arid region of the United States can be redeemed by irrigation, and the segregation of the irrigable lands in such arid region, and for the selection of sites for reservoirs and other hydraulic works necessary for the storage and utilization of water for irrigation and the prevention of floods and overflows, and to make the necessary maps, including the pay of employees in field and in office, the cost of all instruments, apparatus, and materials, and all other necessary expenses connected therewith, the work to be performed by the Geological Survey, under the direction of the Secretary of the Interior, the sum of one hundred thousand dollars or so much thereof as may be necessary. And the Director of the Geological Survey under the supervision of the Secretary of the Interior shall make a report to Congress on the first Monday in December of each year, showing in detail how the said money has been expended, the amount used for actual survey and engineer work in the field in locating sites for reservoirs and an itemized account of the expenditure under this appropriation. And all the lands which may hereafter be designated or selected by such United States surveys for sites for reservoirs, ditches, or canals for irrigation purposes and all the lands made susceptible of irrigation by such reservoirs, ditches, or canals are from this time henceforth hereby reserved from sale as the property of the United States, and shall not be subject after the passage of this act to entry, settlement, or occupation until further provided by law:

Provided, That the President may at any time in his discretion by proclamation open any portion or all of the lands reserved by this provision to settlement under the homestead laws. (Approved October 2, 1888. Stat. L., vol. 25, pp. 526, 527.)

In the following year $250,000 was appropriated for continuing the work. (Approved March 2, 1889. Stat. L., vol. 25, p. 960.)

A portion of the law passed October 2, 1888, was repealed by the following provisions in the act approved August 30, 1890 (Stat. L., vol. 26, p. 391), and no appropriation was made for irrigation work as such:

For topographic surveys in various portions of the United States, three hundred and twenty-five thousand dollars, one-half of which sum shall be expended west of the one hundredth meridian; and so much of the act of October second, eighteen hundred and eighty-eight, entitled "An act making appropriations for sundry civil expenses of the Government for the fiscal year ending June thirteenth, eighteen hundred and eighty-nine, and for other purposes," as provides for the withdrawal of the public lands from entry, occupation and settlement, is hereby repealed, and all entries made or claims initiated in good faith and valid but for said act, shall be recognized and may be perfected in the same manner as if said law had not been enacted, except that reservoir sites heretofore located or selected shall remain segregated and reserved from entry or settlement as provided by said act, until otherwise provided by law, and reservoir sites hereafter located or selected on public lands shall in like manner be reserved from the date of the location or selection thereof.

No person who shall after the passage of this act, enter upon any of the public lands with a view to occupation, entry, or settlement under any of the land laws shall be permitted to acquire title to more than three hundred and twenty acres in the aggregate, under all of said laws, but this limitation shall not operate to curtail the right of any person who has heretofore made entry or settlement on the public lands, or whose occupation, entry, or settlement is validated by this act: *Provided*, That in all patents for lands hereafter taken up under any of the land laws of the United States or on entries or claims validated by this act west of the one hundredth meridian, it shall be expressed that there is reserved from the lands in said patent described, a right of way thereon for ditches or canals constructed by the authority of the United States. (Approved August 30, 1890. Stat. L., vol. 26, p. 391.)

Under this law the Survey selected and mapped a large number of reservoir sites, which have been noted on the records of the General Land Office, and are now reserved from entry or settlement. Descriptions of these sites may be found in the Tenth, Eleventh, Twelfth, and Thirteenth Annual Reports of the Geological Survey.

From the above cited paragraphs it appears that the portion of the original law approved October 2, 1888, which affected the withdrawal of the public lands from entry, occupation, and settlement was repealed, but that the remaining portions of the law were unaffected by the act of repeal, and that there is still on the statute books authority for

making an examination of the arid region of the United States, for ascertaining the capacity of the streams, and "for the selection of sites for reservoirs and other hydraulic works necessary for the storage and utilization of water for irrigation and the prevention of floods and overflows, and to make the necessary maps."

In the repealing act it was specifically provided that the reservoir sites shall remain segregated for such use, and in a law entitled "An act to repeal timber-culture laws, and for other purposes," approved March 3, 1891, it is provided:

> That reservoir sites located or selected and to be located and selected under the provisions of "An act making appropriations for sundry civil expenses of the Government for the fiscal year ending June thirtieth, eighteen hundred and eighty-nine, and for other purposes," and amendments thereto, shall be restricted to and shall contain only so much land as is actually necessary for the construction and maintenance of reservoirs; excluding so far as practicable lands occupied by actual settlers at the date of the location of said reservoirs. (Stat. L., vol. 26, p. 1101.)

CHARACTER OF SURVEYS.

In making surveys and estimates for storage reservoirs the operations fall naturally into two classes or steps: First, ascertainment of the natural conditions; and, second, preparation of estimates based upon these and upon the existing artificial limitations.

In most of the work of this character conducted by the Geological Survey the operations have extended only to the first class—ascertainment of the physical facts; but in some cases the investigations and data have been elaborated to the point of preparing detailed plans and estimates based upon certain assumptions.

The natural conditions to be ascertained in the case of storage reservoirs are primarily those which fall within the observations of the topographers engaged on the map of the United States. These are the area, outlines, slopes, and character of the catchment basin tributary to the reservoir, and the capacity of the latter at various heights of water. Closely joined with this are the operations of the hydrographers in measuring the flow of the stream and ascertaining the volume of water which can be depended upon to reach the reservoir under ordinary conditions, as well as the extreme floods, against which provision must be made. Having ascertained the facts as to the probable water supply, it is then necessary to ascertain the conditions at the proposed dam site, such as the character of the foundation, the materials available, and the length, height, and other dimensions of the necessary structure. These facts have been ascertained from time to time concerning many scores of reservoir sites within the arid region. This work, on a large or a small scale, has been systematically carried forward year by year.

The artificial conditions to which reference has been made, and which must be taken into consideration in preparing detailed estimates, are not susceptible of measurement and final estimates, since they are changing from time to time. These are chiefly land ownership and acquired rights to water, transportation facilities, cost of materials, and, more important than all, the capital available toward the construction of the proposed dam. With unlimited funds at hand the engineer would plan and build a dam entirely different in material and method of construction from one which he must erect when called upon to produce the desired result with an exceedingly small amount of money. In the first case he would look mainly to stability and thoroughness of workmanship; in the second, he would adopt the cheapest devices and

assume certain risks, with the thought that from year to year the temporary imperfections could be remedied, until a time when larger funds might be available. In the first case he might, and probably would, construct the dam of solid masonry; in the second, he might make it of loose rock, or even largely of wood, with the intention of renewing parts in five or ten years, whenever portions of the material showed signs of decay.

From what has been said it is evident that reservoir surveys can be carried on widely to great advantage up to the point of making estimates of cost, and that to go beyond this assumptions must be made, founded on a knowledge as to whether the dams are to be built by individuals for limited use, by associations or corporations for larger purposes, or by the community—the county, State, or nation—to supply the largest possible quantity of water and to have unlimited length of life. Without some such fundamental assumption it is, of course, impossible to make estimates for construction purposes. The Geological Survey has, in some instances, attempted to overcome this difficulty by making estimates, based upon different types of dam—earthwork, loose rock with wooden face, masonry, etc. But the laborious estimates prepared upon various assumptions are largely wasted efforts, and will continue to be until it is apparent whether these reservoirs will be constructed by individuals or associations, and hence with a small capacity, or by the community, for maximum service and with commensurate stability.

The character of various estimates of cost can best be illustrated by the case of a public building such as a court-house. It is obvious that in order to prepare a final estimate for construction, certain details—as number and size of rooms, plumbing, and interior finish—must be definitely settled upon, as well as the external appearance. These in turn depend upon the financial condition of the county. When these points are made plain, it is possible to prepare detailed estimates as to the total cost of the building. If, on the other hand, a builder is told that a county court-house is needed, but is given no information as to the amount of money that can be expended, or the requirements, he can merely state that in round numbers a good building can be erected for $100,000. Thus it is with estimates for construction of dams. Knowing the size of the reservoir and the natural conditions existing at the dam site, the engineer can merely state that a dam can be built for so many thousand dollars, in round numbers. He may go further and prepare estimates for an earthwork dam, or a wooden-sheathed loose-rock structure, or a solid masonry barrier; but these estimates can not be considered final until other conditions, mainly of a financial character, are known.

It was early recognized that detailed estimates of the cost of construction of dams are of little use until some definite decision has been reached as to probable construction. The preparation of these estimates was therefore discontinued, and efforts were directed to the ascertainment of the natural conditions. These are of prime importance. The necessity of expending funds in ascertaining where reservoir sites are located, and their size and value, can not be gainsaid. Data of this kind are the foundation for any broad classification of the public domain, and for ascertaining the extent to which the arid lands can be redeemed by irrigation. They are inseparably connected with questions concerning flow of streams and quantity of available water. The acquisition of the facts does not in any way depend upon assumptions as to how the reservoirs are to be constructed, and the results

are equally valuable whether the work is ultimately performed by individuals, by associations, or by the State. They enable each citizen to determine for himself where reservoir sites exist, and, in a general way, whether a dam can be constructed to financial advantage.

The method of survey has been that which experience has shown to be the most expeditious and economical. The plane-table is used almost exclusively, elevations being checked by precise leveling. In this way results of accuracy are obtained at an expenditure of one-half or one-fourth the time employed in the usual way of transit location and of plotting notes. The scale employed has been dependent upon the size of the reservoir, the attempt being usually made to complete the map upon the plane-table in ordinary use. The contour interval has usually been 10 feet, although in special cases a 5-foot vertical interval has been used.

At the dam sites it has usually been the custom to prepare a map still more detailed than that of the reservoir, in order to show minor inequalities of surface. The scale employed has been governed by the proposed site, and the contour interval has ranged from 1 foot to 5 feet, thus bringing out minor inequalities of surface and affording means of computing the cubical contents of the dam above the original surface. Wherever practicable, notes have been made as to the probable amount of earth or loose rock to be removed in preparing foundations.

The resulting plane-table sheets have been carefully completed for preservation and placed among the records of the office of the Geological Survey. Photographs of these are made at once, and in most instances the drawings have been reproduced in generalized form in Annual Reports of the Geological Survey.

EXTENT OF SURVEYS.

The extent of reservoir surveys can best be shown by reference to the Annual Reports of the Survey, beginning with the Eleventh, Part II. In order to assemble these data in concise form, the following tables have been prepared, giving reference to the volume and page where additional facts can be found. A few of the principal details have been assembled in the table to afford a general conception of the character of the reservoirs examined.

ARIZONA.

In Arizona the principal reservoir surveys have been those made on Gila River and its tributaries and described in Senate Document No. 27, Fifty-fourth Congress, second session; also, in less detail, in the Eighteenth Annual Report, Part IV, on pages 291 to 297. Detailed estimates have been prepared for the construction of two dams, under the assumption that one of these may ultimately be built by the Government, mainly for the purpose of supplying water to the Indians. Other surveys of reservoirs on the head waters of Salt and Verde rivers have been made by private parties. These are described in a general way in the Senate document mentioned above.

CALIFORNIA.

In this State most of the reservoir surveys have been made within the high Sierras, in the vicinity of Lake Tahoe, these being on the head waters of Truckee River, flowing into California; also on the head waters of Stanislaus, Tuolumne, and Merced rivers, flowing into San Joaquin Valley. A general description of these is given in the Eleventh

Annual Report, Part II, on pages 150 to 168. The engineering details and estimates are more fully discussed in the Thirteenth Annual Report, Part III, on pages 398 to 409. The following table gives in condensed form the principal facts concerning the reservoirs examined or surveyed in this State. In the second column is given the page reference to the Annual Reports, where additional facts may be found; in the next column is given the arbitrary number, and in the fourth column is given the name of the reservoir or stream to which the reservoir is tributary. The drainage area above the reservoir site is also given, and the approximate altitude of water surface. An assumed height of dam is also stated, and the area of the water surface in acres, which will be formed by a dam of this height; also the total capacity of the reservoir in acre-feet.

Surveys of reservoir sites in California.

Annual report.	Page.	No.	Name.	Drainage area.	Altitude.	Height of dam.	Area of reservoir.	Capacity of reservoir.
				Sq. miles.	*Feet.*	*Feet.*	*Acres.*	*Acre-feet.*
13	405	1	Clear Lake *a*	.....	.....	.....	46,080	435,300
13	391	2	Independence Lake *b*	.....	6,997	40	984	23,707
13	392	3	Webber Lake *b*	.....	6,769	29	778	11,152
13	389–390	4	Donner Lake *a*	.....	6,095	26	1,337	22,205
			Donner Lake and Cold Creek	.....	6,095	33 98	2,006	42,827
12	10	5	Yuba River	6	6,700–8,300	20	320	2,400
12	12	6	Squaw Creek	12	6,100–9,000	16	225	1,350
13	400	7	Little Yosemite or Merced River *a*	.....	5,980	115	841	45,195
13	400	8	Lake Tenaiya *a*	.....	7,990	59.5	597	23,082
13	400	9	Tuolumne Meadows *a*	.....	8,339	75	1,081	43,185
13	400	10	Lake Eleanor *a*	.....	4,561	65 89	1,127	93,060
13	400	11	Kennedy Meadow *a*	.....	6,911	55	348	6,917
13	400	12	Kennedy Lake *a*	.....	8,009	31	110	2,018
13	400	13	Bear Valley on Bloods Creek *a*	.....	6,182	81	128	4,608
12	13	14	Red Lake	Small	7,850–9,500	35	80	1,050
12	14	15	Markleeville Creek	do	5,900–8,500	*c*35	60	790
12	16	16	East Carson River	.....	6,000–11,000	65	40	975
12	17	17	Deer Creek	Indefinite.	8,000	22	20	160
12	17	18	Heenan Lake	Small	7,100–8,000	30	130	1,460
12	19	19	Silver Creek	.....	6,400–11,000	60	255	5,740
12	20	20	Wolf Creek	.....	6,500–11,000	65	190	4,630
12	21	21	East Carson	Extensive.	6,600–11,000	65	225	5,480
12	23	22	Mokelumne River	.....	7,000–10,000	40	75	1,120
12	24	23	do	.....	6,800–10,000	38	30	430
12	25	24	Pacific Valley Creek	Small	7,500–9,500	35	75	980
12	26	25	Big Canyon Creek	.....	5,500–7,500	23 60	280	6,300
12	27	26	do	.....	5,000–8,000	35	175	2,200
12	28	27	Hull Creek	.....	5,000–6,000	50	115	2,160
12	30	28	Granite Creek	.....	5,000	40	220	3,300
12	31	29	Cherry River	.....	4,500–11,000	40	165	2,500
12	33	30	Lake Vernon	.....	6,500	30	480	5,700
12	34	31	Big Meadow site *d*	Small	7,500	30	980	11,000
12	35	32	Errars Meadow site *e*	do	5,000	7 30	95	1,070
12	36	33	Tuolumne River	Large	1,500–12,000	100	680	25,500
12	38	34	Little Truckee River	.....	6,500–9,000	60	450	10,100
12	39	35	do	.....	5,800–9,000	50	120	2,250
12	40	36	Prosser Creek	12	6,200–9,000	30	310	3,480
12	42	37	Little Truckee River	.....	4,500–9,000	50	350	6,500
12	43	38	Monument Peak site *e*	Small	7,700–10,000	80	160	4,800
12	45	39	Near East Carson River	.....	5,200–11,000	60	150	3,370
12	46	40	Grass Lake	Small	7,800–9,500	30	350	4,000
12	47	41	West Fork Carson River	Large	5,000–12,000	150	2,400	(*f*)
12	51	42	Near West Fork Carson River	Small	5,500–6,300	40	40	600
12	52	43	Silver Fork American River	do	7,800	47	135	2,400
12	53	44	Near Silver Fork American River.	.....	7,900	30	420	4,700

a See also Eleventh Annual Report, Part II, pp. 150 to 168.
b See also Eleventh Annual Report, Part II, p. 174.
c Consists of two sites with separate dams of same height.
d On small creek in Tuolumne County.
e In Tuolumne County.
f Not estimated.

COLORADO.

Most of the reservoir surveys in Colorado have been confined to the head waters of Arkansas River. A general description is given in the Eleventh Annual Report, Part II, on pages 133 to 144, and the engineering details are noted in the Thirteenth Annual Report, Part III, on pages 357 to 370. The relative location of the reservoirs and of the streams into which their waters empty is shown on a large folded map accompanying the volume. The following list gives the principal details concerning the sites examined:

Surveys of reservoir sites in Colorado.

Annual Report.	Page.	No.	Name.	Drainage area.	Altitude. (*a*)	Height of dam.	Area of reservoir.	Capacity of reservoir.
				Sq. miles.	*Feet.*	*Feet.*	*Acres.*	*Acre-feet.*
13	365	1	Twin Lakes *b*	387	9,240	73	3,475	103,500
13	365	2	East Fork Arkansas River	.....	10,000	105	.....	8,875
13	365	3	Clear Lake	.....	.....	30 65	.....	7,000
13	365	4	Hayden	.....	9,240	120	.....	45,000
13	365	5	Sugar Loaf	.....	10,000	105	.....	8,875
12	55	6	Seven Mile Creek	30	8,400	100	160	4,550
13	365	7	Tennessee Fork of Arkansas River	.....	9,870	68	.....	37,000
12	56	8	Grape Creek	380	8,000	140	2,540	119,100
12	58	9	Pine Creek	30	7,900	100	80	1,520
12	59	10	Slate Creek	25	8,100	86	560	8,570
12	61	11	West Oil or Ten Mile Creek	20	8,500	67	200	2,250
12	62	12	Oil Creek	160	8,500	159	1,400	56,200
12	64	13	West Beaver Creek	60	9,000	96	1,320	28,450
12	66	14	Beaver Creek	25	9,000	63	50	620
12	67	15	Oil Creek	270	5,800	100	167	4,300
12	69	16	Wilson Creek	35	5,900	90	80	2,900
12	70	17	Sand Creek	30	5,450	84	115	1,950
12	72	18	Six Mile Creek	*c* 180	5,500	100	50	3,100
12	73	19	Eight Mile Creek	50	5,500	70	210	4,540
12	74	20	Beaver Creek	130	5,100	.....	215	7,100
12	76	21	Turkey Creek	70	5,400	80	520	9,800
12	78	22	.....do	70	5,000	60	90	1,920
12	79	23	Arkansas River	.....	4,900	90	1,920	359,000
12	83	24	Rush Creek	10	5,400	50	335	2,100
13	365	25	Cottonwood Lake	.....	.....	110	.....	8,400
12	84	26	St. Charles River	180	4,980	27	170	2,640
12	85	27	.... do	65	6,300	77	200	3,340
12	87	28	Graneros Creek	*d* 50	6,000	165	760	27,200
12	88	29	Huerfano River	500	6,895	49	115	1,960
12	89	30	Cucharas River	40	7,800	132	130	4,125
12	91	31	Arapahoe River	25	7,200	139	450	13,300
12	92	32	Santa Clara River	45	6,700	142	420	10,150
12	94	33	Apishapa River	100	6,850	115	440	12,790
12	96	34	Purgatory River	320	6,620	120	450	6,200
12	97	35	In Stonewall Valley	50	8,300	135	240	11,200
12	98	36	Purgatory River	65	8,200	142	760	22,700
12	100	37	Apishapa River	420	5,600	31	250	3,840
13	365	38	Monument Creek	.....	6,950	47	.....	5,630
13	365	39	Pring	.....	.....	83	.....	.....
12	101	40	Smith Canyon Creek	220	4,700	98	1,400	34,230
12	103	41	Rule Creek	140	4,250	68	1,560	32,780
12	105	42	Cottonwood Creek	110	4,300	58	1,000	25,680
12	106	43	Two Butte Creek	250	4,500	50	480	5,900
12	107	44	Supplied from Arkansas River *e*	None	4,250	20	700	14,720
12	109	45	Supplied from Arkansas River *f*	Small	4,150	None	1,680	21,470
12	111	46	Supplied from Arkansas River *g*	.....do	4,150	None	4,160	73,300
12	113	47	Tennessee Fork, Arkansas River	20	10,600	50	420	9,600
12	115	48	East Fork Arkansas River	30	10,100	45	250	4,100
12	116	49	Pine Creek	20	8,545	60	130	2,500
12	117	50	.....do	25	8,600	70	90	1,500
12	119	51	Arkansas River	600	8,000	120	420	11,940
12	120	52	Oak Grove Creek	30	6,425	84	80	1,310
12	122	53	Rock Creek	30	5,200	70	300	6,600
12	124	54	Timpas Creek	75	4,950	88	840	13,640
12	125	55	Las Animas River	2,400	4,450	108	2,360	43,330

a Elevations refer to approximate altitude of reservoirs.
b See Eleventh Annual Report, Part II, p. 135.
c Includes drainage of Eight Mile and Beaver creeks.
d Includes drainage of Greenhorn Creek.
e Depression on the open plains, 6 miles east of Rocky Fork.
f Depression on the open plains, 8 miles south of Kilburn.
g Depression on the open plains, 10 miles southeast of Arlington.

IDAHO.

In this State reservoir surveys have been made on the head waters of Snake River, and to a less extent on streams flowing into this river from the north, in the southwestern part of the State. A general description is given in the Eleventh Annual Report, Part II, on pages 190 to 200, and the engineering features are discussed in the Thirteenth Annual Report, Part III, on pages 422 to 427. Later surveys of reservoir sites on Blackfoot River are given in the Eighteenth Annual Report, Part IV, on pages 330 to 333. Other reservoir surveys will be described in the Twentieth Annual Report, now in preparation.

MONTANA.

In Montana the most extensive surveys were made of Sun River, as described in the Eleventh Annual Report, Part II, on pages 113 to 133, and also in the Thirteenth Annual Report, Part III, on pages 371 to 386. The principal details concerning other reservoir sites are given in the following table, with reference to the volume where additional facts may be had:

Survey of reservoir sites in Montana.

Annual Report.	Page.	No.	River.	Drainage area.	Altitude.	Height of dam.	Area of reservoir.	Capacity of reservoir.
				Sq. miles.	*Feet.*	*Feet.*	*Acres.*	*Acre-feet.*
13	374	1	North Fork Sun River[a]	1,172	.....	16 57	275	5,250
13	375	2	Sun River	1,136	.....	99	370	13,105
13	376	3	North Fork Sun River	668	.....	121	1,100	51,400
13	377	4	.....do	318	.....	113	581	20,315
13	378	5	Willow Creek	87	.....	84	1,600	38,600
13	379	6	.....do	37	.....	22	378	6,550
13	380	7	Near Willow Creek[b]	Small.	.....	41	293	5,590
13	381	8	1 mile north of reservoir No. 7	.....do	.....	23	140	2,091
13	382	9	Below canal No. 2	None	.....	35	72	812
13	382	10	Benton Lake	.....	3,610	None.[c]	9,130	140,000
12	127	11	Flat in Meagher County[d]	10	5,000	15	30	160
12	128	12	Near Martinsdale[e]	.....	4,900–7,600	40	40	800
12	129	13	Daisy Dean Creek	40	5,000–8,000	15	20	105
12	131	14	East Branch Daisy Dean Creek	18	4,800–8,000	35	30	390
12	132	15	North Fork Musselshell River	60	5,400–8,000	35	40	520
12	133	16	South Fork Musselshell River	95	5,000–8,500	55	100	.....
12	133	17	.....do	.....	5,100–8,500	20	25	.....
12	134	18	Sixteen Mile Creek	90	5,500–7,000	50	1,055	19,781
12	137	19	South Fork Smith River	12	5,600–7,000	25	120	1,125
12	139	20	.....do	50	5,300–7,000	30	110	1,230
12	140	21	Basin in Meagher County[f]	.....	4,000	10	15	.....
12	141	22–23	Basin on Mitchell Creek	.....	.....	15	50	.....
12	142	24	Big Hole River	.....	5,000–10,000	100	11,800	.....
12	147	25	Black-tail Deer Creek	.....	6,000–10,000	40	600	.....
12	148	26	Beaver Head River	.....	5,400–10,000	125	1,400	.....
12	150	27	Red Rock River	.....	.....	40	1,200	.....
12	152	28	Ruby River	.....	5,300–10,000	35	400	.....
12	153	29	Alkali Basin[g]	.....	.....	20	2,800	.....
12	155	30	Dry Lake[g]	.....	.....	15	200	.....
12	156	31	Box Elder Creek	85	3,600–7,000	46	180	3,000
12	158	32	West Fork Otter Creek	.....	5,000–7,000	66	70	1,500
12	159	33	Sage Creek	25	4,900–8,000	21	30	250
12	160	34	Middle Fork Judith River	120	5,000–8,000	76	100	3,000
12	161	35	Dry Basin in Fergus County[h]	.....	4,900	.....	35	200
12	162	36	Dry Lake Basin, Fergus County[i]	.....	4,900	3	55	350
12	163	37	Lebo Lake	.....	5,000–9,000	10	.....	.....
12	164	38	Flat in Meagher County[j]	.....	6,000–8,000	35	250	.....

[a] See also Eleventh Annual Report, Part II, pp. 123–125.
[b] 2 miles west of reservoir No. 5.
[c] To be drained by a cut 1¼ miles long and 35 feet maximum depth.
[d] 2 miles above Martinsdale.
[e] Near North Fork Musselshell River.
[f] 3 miles west of Confederate Gulch.
[g] Choteau County.
[h] 2½ miles north of Utica.
[i] 1½ miles north of Utica.
[j] 1½ miles above Martinsdale.

NEVADA.

The principal reservoir sites examined for the benefit of this State lie in California, on or near the head waters of the Truckee, Carson, and other streams flowing from California into Nevada. These have been described under the head of "California." The details can be found in the Eleventh Annual Report, Part II, on pages 168 to 182, and in the Thirteenth Annual Report, Part III, on pages 387 to 397.

Surveys of reservoir sites in Nevada.

Annual Report.	Page.	No.	River.	Drainage area.	Altitude.	Height of dam.	Area of reservoir.	Capacity of reservoir.
				Acres.	*Feet.*	*Feet.*	*Acres.*	*Acre-feet.*
12	209	1	Truckee River	1,000	4,200–10,800	50	400	7,500
12	210	2	do	1,000	4,200–10,800	60	395	7,400
13	394	17	Long Valley Creek			60 100	1,086	34,425
13	395	18	West Carson River		7,050	163	1,800	90,810

NEW MEXICO.

A considerable number of small reservoir sites have been examined in this Territory, but comparatively few of these have been surveyed in detail. The results are given in the Eleventh Annual Report, Part II, on pages 145 to 150, and in the Twelfth Annual Report, Part II, on pages 165 to 208.

Surveys of reservoir sites in New Mexico.

Annual Report.	Page.	No.	River.	Drainage area.	Altitude.	Height of dam.	Area of reservoir.	Capacity of reservoir.
				Sq. miles.	*Feet.*	*Feet.*	*Acres.*	*Acre-feet.*
12	165	1	Horse Lake			40	1,120	21,000
12	166	2	Boulder Lake		7,500	100	2,250	51,000
12	168	3	Stinking Lake		7,500	50	3,630	125,000
12	169	4	Vallecitos Creek		7,000–8,000	100	100	3,500
12	169	5	Near El Rito		7,000–8,000	150	60	3,000
12	170	6	Rio Vallecitos		7,000	80	60	1,800
12	171	7	Rio Caliente		7,000–8,000	80	330	10,000
12	173	8	Rio Hondo			100	50	1,000
12	173	9	Rio Colorado		8,000	100	270	9,000
12	174	10	Rio Picuris		7,000–8,000	60	62	1,200
12	175	11	Rio Picuris and Rio Lusio		7,000–8,000	80	236	6,000
12	175	12	Rio Grande		6,000–13,000	50	1,500	30,000
12	177	13	East Fork of Rio Jemez				4,030	18,000
12	177	14	Rio Jemez		9,000–10,000	53½	256	5,000
12	178	15	do		8,500–11,000	57	212	4,500
12	179	16	do		8,500–11,000	58	575	13,000
12	180	17	do			70	1,046	32,000
12	180	18	Rio Salado		7,000–9,000	60	155	3,700
12	181	19	Rio Jemez			90	1,640	60,000
12	182	20	Santa Fe Creek		8,000–12,000	72	40	1,100
12	183	21	Rio Medio and Rio Frijole		6,000–10,000	50	45	800
12	183	22	Rio Mora		7,000–10,000	60	620	5,400
12	184	23	do		7,000–11,000	90	1,770	38,000
12	185	24	Manuelitos and Las Tusas creeks		6,700–10,000	100	1,037	41,000
12	186	25	Supplied from Rio Mora		6,000–10,000	None.	800	15,000
12	188	26	Rio Gallinas		6,000–7,000	100	170	5,800
12	189	27	Rio Pecos		7,000–12,000	75	370	8,800
12	190	28	do		7,000–11,000	82	250	7,800
12	191	29	Rio Grande		6,000–12,000	31	4,452	87,000
12	192	30	Rio San Jose		6,000–8,000	46	900	20,000
12	193	31	San Mateo Creek		6,000–8,000	43½	380	5,500
12	194	32	Blue Water Creek		7,000	19	490	3,000
12	195	33	do		7,000–9,000	74½	1,900	53,000
12	198	34	Agua Fria Creek		7,000–9,000	21 24 36	82 83 128	680 660 1,400
12	199	35	Rio Colorado		6,000–7,000	72	420	1,100
12	200	36	Rio Salado		6,000–8,000	68	2,800	63,000
12	202	37	Rio Alamosa		6,000–7,000	125	1,185	59,000
12	203	38	Rio Grande			80	5,540	175,000
12	208	39	do			40	6,380	102,000
13	410	....	do		3,778	65	26,000	537,000

UTAH.

Reservoir surveys in this State have been made on the two great fresh-water lakes, Bear and Utah. The results of the survey of Utah Lake are given in the Eleventh Annual Report, Part II, on pages 70 to 74 and 183 to 184. The conditions are also discussed in the Twelfth Annual Report, Part II, on pages 334 to 339. The survey of Bear Lake is described in the Twelfth Annual Report, Part II, on pages 327 to 329, and in the Thirteenth Annual Report, on page 452. In addition to these examinations have been made of reservoir sites mainly along the Sevier and its tributaries, as described in the Thirteenth Annual Report, Part III, on pages 451 to 478.

Surveys of reservoir sites in Utah.

Annual Report.	Page.	No.	River.	Drainage area.	Altitude.	Height of dam.	Area of reservoir.	Capacity of reservoir.
				Acres.	*Feet.*	*Feet.*	*Acres.*	*Acre-feet.*
13	452	1	Bear Lake	250	6,000–10,000	.....	69,120	208,000
13	458	2	Silver Lake	3	8,600	52	140	2,500
13	460	3	Twin Lakes	3	9,000	20	25	450
13	460	4	Marys Lake	3	9,000	25	25	550
13	461	5	Sevier River	5,000	4,600	16	940	10,000
13	463	6	Sanpitch River	500	5,100	22	830	9,000
13	465	7	Sevier River	2,500	5,700	10	290	1,600
13	466	8	East Fork, Sevier River	700	6,200	12½	460	3,000
13	468	9	Otter Creek	500	6,200	15	1,860	14,000
13	470	10	East Fork, Sevier River	575	7,000	50	3,050	76,000
13	473	11	.....do	300	7,200	10	770	3,500
13	475	12	Panguitch Lake	80	8,100	10	1,280	10,700
13	477	13	Blue Spring *a*	25	8,200	48	440	13,000

a Two miles southwest of Panguitch Lake.

PRESENT CONDITIONS.

From the foregoing statements and tables it appears that a large number of reservoir sites have been discovered, many of these surveyed, and for some of them definite estimates prepared, based upon certain assumptions as to the character of dam needed. The bringing of these to public attention has resulted in much correspondence regarding their use and in discussion, both public and private, as to the opportunities for water conservation. In a few instances the dams have been constructed and the reservoirs are now supplying the needed water to lands under irrigation, but in the majority of cases no action has resulted. This is particularly true with the larger or more valuable of the sites, the water from which must be distributed among a number of ditches or communities. The great cost involved and the doubts as to methods of equable distribution of the water are such as to cause indefinite delay.

One fact has come prominently forward during the last ten years, since the inauguration of the reservoir work, and that is that water storage on a large scale can rarely be made profitable to individuals or corporations. Water conservation is expensive at best, and existing conditions, laws, and customs are such that the person who builds a dam on the head waters of a stream is rarely in a position to be benefited financially by the water which he impounds. The capitalists who have put their money into such enterprises have involuntarily become philanthropists—benefactors of their fellow-men, but not gainers themselves to a notable degree. The community as a whole is unquestion-

ably enriched, directly or indirectly, to an extent many times the first cost of the works, but these benefits can not redound wholly to the constructors. When the reservoir surveys were begun it was believed by many persons that the sites would be eagerly seized upon and that construction would immediately follow; but, out of many possible localities, very few have been found to be so favorably situated as to attract investors. Nevertheless, the discovery of these few is undoubtedly worth the expenditure.

While reservoirs in general can not be made sources of profit to the investors, there is no gainsaying the fact that they are indispensable to the community. They may be classed with light-houses and works of internal improvement, which, under existing laws and customs, can not be made sources of private gain, and yet must be had if a full development of the natural resources is to be obtained.

The one great demand of the western half of the United States is for more water during times of scarcity. This has been particularly accentuated by the droughts of 1898, when millions of dollars were lost through lack of ordinary supply. It is highly probable that the aggregate losses to the communities, if these could have been put in the form of works for conserving flood water, would have repaid the cost of all such works. Such losses are so distributed and so far-reaching that it is, of course, impossible to segregate them, or to indicate definitely the individuals most deeply concerned. They are, moreover, of such character that only the community as a whole is competent to guard against them, individual, or even corporate action, not being possible. The State or the nation must provide the means by which disasters of this kind may in the future be avoided. Ten years ago it was commonly asserted that every acre of the arid land could be reclaimed. Now there is no longer talk of irrigating every acre of the fertile lands of the arid region, and comparatively little interest is displayed as to whether 10 or 15 per cent of these lands can be reclaimed. Public sentiment is now concentrated on the question how the relatively small quantity of water can be conserved for the largest use, it being apparent that by such conservation a population of many million can be directly or indirectly sustained.

The stream measurements carried on at various typical localities have been so diffused as to afford as much data as possible concerning the water resources of the country. They have shown that for many localities there has been sufficient water flowing at times of flood, and inferentially that similar conditions exist elsewhere. There is thus no question as to the fact that in general a large quantity of water exists in spring, and that this can be held in certain reservoirs, at least until time of need; but the question still unanswered is, By what means can this water conservation be brought about?

To sum up the present conditions of reservoir surveys, it may be stated that at scattered localities throughout the great arid region numerous reservoir sites have been surveyed, and that some of these have been constructed. Others still more important may be built, but probably this can not be done with direct financial profit. The great body of the public lands has not yet been examined in detail, but as fast as means will permit reservoir surveys are being conducted on a small scale. These should be extended whenever practicable. The United States is still the owner of one-third of its whole area, exclusive of Alaska—an area three times as great as the thirteen original States. This one-third contains not only great resources in minerals and grazing, but also immense tracts of rich agricultural lands capable of supporting

a population of many millions wherever sufficient water can be had. The utilization of this public land or any considerable portion of it, and the development of the resources of the western half of the country are practically at a standstill, owing to the lack of water conservation. The measurements of this survey have shown that during each year great volumes of water run to waste, much of which could be held by storage in natural reservoir sites already surveyed or believed to exist among the high mountains and upon Government land. In order to utilize these sites, whether by the individual or by the community, it is necessary to continue and extend accurate surveys and obtain correct information as to location, capacity, and probable cost of construction.

REQUISITES FOR SUCCESS.

In estimating the possible use or value of various reservoir sites there are many considerations which must be borne in mind. Some of these modify, if they do not completely prevent, the utilization of the reservoir. Remarks have already been made upon the fact that financial failure is not incompatible with the success of a reservoir in other ways. That is to say, a reservoir may be of very great benefit, returning to the community many times its first cost, and yet not pay its owners. Without dwelling upon this detail, it is necessary to consider some of the conditions which must be fulfilled in order to result in the reclamation of arid lands.

In almost every locality a number of places are pointed out as being suitable for water conservation. Hundreds of these have been examined, and comparatively few have been found worthy of survey. As a rule, inspection shows that the capacity of the basin is too small for the height of the proposed dam; or, in other words, that the slope of the bottom of the reservoir is too great. This is the most common source of error, as very few people appreciate the rapid slope of upland valleys. To hold water in some of these would require a dam so high as to be entirely out of the question.

Favorable conditions for the erection of a dam are also necessary. It occasionally happens that, in order to inclose a basin of sufficient capacity, the length of dam will be so enormous as to be impracticable; in other cases the foundations must be placed in unconsolidated or fractured material, necessitating excavations of great depth. Some of the gorges draining valleys have been at a previous time excavated below their present surface, and the filling of sand and gravel extends to extraordinary depth.

Where the combination of ample capacity and a good locality for dam exists, it may happen that there is not sufficient tributary watershed to furnish an ample supply for filling the reservoir each year. Many of the best open valleys, or marshes, exist so near the summits of the mountains that there is not a sufficient catchment area. In such cases it is sometimes possible to divert water from one or more upper-drainage basins, and by flumes and tunnels to concentrate this into the desired reservoir site.

On the other hand, the reservoir may be so situated as to have a catchment area too great for safety. This is particularly the case where a dam is located upon a main drainage line receiving storm waters from many square miles. A cloud-burst or general storm may send down a flood of such dimensions as to fill the reservoir and overtop the dam, washing it away, if of earth, as was the case at the time of the Johns-

town flood. To meet such emergencies there must be opportunity for the construction of enormous wasteways around the dam, or, if these can not be built, the dam itself must be made of such substantial masonry that water can pour over its top, as has been the case with the Sweetwater dam of southern California.

Although the dam and the wasteways may be of such character as to withstand the onset of any flood, there is still another danger to be guarded against, and that is the bringing down of vast quantities of sand, gravel, and clay, which are dropped in the comparatively still water behind the dam, thus gradually filling the reservoir and destroying its usefulness. There is no economical method of cleaning out a reservoir of large size, and when once filled it must probably be abandoned.

As a safeguard against floods and against silting up the reservoir, attempts are made wherever practicable to find sites upon smaller tributaries and to conduct water to these from the main stream by means of large diversion canals. In this way the flood waters can be received with safety, as their quantity is restricted by the capacity of the canal, and most of the silt is dropped on the way and disposed of by means of various well-known engineering devices.

From a consideration of these and other qualifications it is apparent that out of the large number of reservoirs examined very few can be expected to possess the elements of success. Thus it is necessary to go over the country with considerable thoroughness and to consider many questions before it is possible to point out the localities where the largest results can be obtained with a reasonable expenditure. It is this fact—that good reservoir sites are scarce—that renders it imperative to push forward the reconnoissance map of the West, and to follow this by detailed examinations by which it is possible to point out the localities where construction work may be attempted with reasonable assurance. In the following paragraphs the more important sites, filling many of these conditions, are designated.

IMPORTANT RESERVOIR SITES.

Upper Missouri Basin in Montana and North Dakota.—Surveys and examinations of reservoir sites along streams tributary to the upper Missouri have been described in the Annual Reports of the Geological Survey, particularly in the Thirteenth Annual Report, Part III, pages 371 to 386, where the Sun River system is described. Ten reservoirs were examined and estimates prepared of cost of construction. Of these, one has already been built, in part, at least; but others in the mountains can be constructed to great advantage to the irrigable lands. The more expensive of these may be left out of consideration.

Upper Missouri Basin in Wyoming.—Surveys of reservoirs on the watershed of Piney Creek, Wyoming, were made by Mr. Fred Bond, under the direction of Capt. Hiram M. Chittenden, Corps of Engineers, United States Army. The results are given in Document No. 141 of the House of Representatives, Fifty-fifth Congress, second session, and a table of estimates gives cost of reservoirs at Cloud Peak, Piney, and Lake De Smet. Captain Chittenden has recommended that, in case reservoir construction is begun, this system should be the first considered.

Platte Basin in Wyoming and Colorado.—The surveys in this basin were made by Mr. F. B. Maltby, under the charge of Capt. Hiram M. Chittenden, Corp of Engineers, and are reported in the volume above

named, giving cost and capacities. One of these sites is near the town of Laramie, Wyo., for storing waters of Big and Little Laramie rivers, and the other on Sweetwater River, at a point about 65 miles due north of the town of Rawlins, Wyo. Two systems of reservoirs in Colorado were surveyed under the direction of Captain Chittenden, as above noted, one being on the South Branch of Platte River, about 20 miles above the junction of the North and South branches, and the other near Loveland, between the valley of Cache la Poudre River and Big Thompson Creek.

Arkansas Basin in Colorado and Kansas.—Arkansas River, rising in Colorado and flowing into Kansas, offers some of the most important problems of water storage in the West and of rights to the waters of a stream flowing across State boundaries. Detailed surveys of the head waters of this stream have been made and the results given, particularly in the Thirteenth Annual Report, Part III, on pages 362 to 370, where estimates may be found. A map showing the general locations of the reservoir sites has been printed as Pl. CXLVII of the above-named report. Some of the reservoirs, notably that of Twin Lakes, are now under construction, but others should be built in order to utilize the full capacity of the river. Particular attention is called to the group of reservoirs in the vicinity of Leadville and those upon the head waters of Grape Creek, Oil Creek, Beaver Creek, etc.

Rio Grande Basin in Colorado and New Mexico.—A large number of reservoirs have been surveyed in the drainage basin of Rio Grande. The general conditions have been described in the Twelfth Annual Report, Part II, on pages 240 to 290. The examinations of reservoirs within this district were made in part by Mr. W. W. Follett, who later became engineer for the International Water Boundary Commission and continued his examination of the Upper Rio Grande as a whole. In Senate Document No. 229, Fifty-fifth Congress, second session, Mr. Follett shows that at six reservoir sites which may be at some time improved water can be held to the amount of 433,000 acre-feet. These are described on page 105 of the report named, this information being of later date than the reports of the Geological Survey on the subject.

Colorado River drainage in Arizona.—Several surveys have been made of reservoir sites in Arizona, the results, with estimates, being given in Senate Document No. 27, Fifty-fourth Congress, second session. The largest of these is of the reservoir at the Buttes, whose cost, as stated on page 56, will aggregate over $2,000,000. An alternative plan for a reservoir at Queen Creek has been submitted, the cost of which will be $221,000.

Bear River drainage in Utah and Idaho.—A reconnoissance was made of the head waters of Bear River in 1889, and later a survey of Bear Lake, which lies partly in Utah and partly in Idaho. This lake serves as a regulator of Bear River, receiving the surplus water in time of flood and allowing it to escape during high water. Its value, however, can be greatly increased by regulating works to throw the full flood of the upper catchment area into the lake and to permit of the lake being drawn to a lower level. The conditions are described in the Eleventh Annual Report, Part II, pages 66 to 70, and in the Twelfth Annual Report, Part II, pages 327 to 334. In the latter report it is shown that north of the lake there is a marsh, this being separated from the open water by a sand ridge about 5 miles in length and from 100 to 300 feet in width. By artificially raising this sand ridge and dredging out the channel, water can be held at a higher level, and at the same time the marsh can be drained and be made useful for cultivation.

Interior basin in Nevada.—The reservoir surveys made in what was known as the Lahontan Division have been described in the Eleventh Annual Report, Part II, on pages 168 to 183. The results are further discussed in the Thirteenth Annual Report, Part III, on pages 387 to 397, and a map showing the relative location is given as Pl. LXXXVI, facing page 152 of the Eleventh Annual Report, Part II. As will be noted, the most important reservoir sites for Nevada lie to the west of the State line in California, particularly Donner Lake, whose maximum capacity may be increased to over 42,000 acre-feet, the cost varying according to the location and character of the dam, as shown on page 391 of the Thirteenth Annual Report, Part III.

In addition to the reservoir sites on the east side of the high Sierras, there are also several important localities on or near Humboldt River, examined by private parties, the results of which examination have not been made public. The construction of these will be of great value in regulating the stream flow and holding back the excess floods.

Columbia River drainage in Idaho.—The larger and more important of the reservoir sites in Idaho are those at or near the head waters of Snake River. In particular should be mentioned the Blackfoot reservoir site, examined by the Geological Survey in 1896, and described in the Eighteenth Annual Report, Part IV, on pages 330 to 333. This locality is about 40 miles southeast of Blackfoot, Idaho. The site is excellent, and with a 50-foot dam 2,060 acres could be flooded. The top length of a dam of this height will be 470 feet, and the bottom width about 300 feet. The total capacity at the 50-foot level will be 545,300 acre-feet.

Another reservoir site examined by the Geological Survey is that noted in the Eleventh Annual Report, Part II, in Swan Valley, which has a storage capacity of about one and a half million acre-feet. Higher up on the same stream—the South Fork of Snake River—a reservoir might be made at Jacksons Lake with a capacity of half a million acre-feet; while on Falls River, a branch of the North Fork, is a third site, with a capacity of half a million acre-feet. (Page 190.) Swan Valley could be made into one of the largest reservoirs in the United States by constructing a dam across the narrow gorge at the outlet to a height of 100 feet.

Columbia River drainage in Oregon.—The reservoir sites of most immediate importance in Oregon are those to be found along the head waters of Wallawalla River, which flows westerly from Blue Mountains into Columbia River, and on the Malheur and Owyhee rivers, flowing northeasterly into Snake River. The water supply along these streams has been discussed in various annual reports of the Geological Survey, and it has been pointed out that, while there is an excess during spring, a general deficiency prevails during summer. It has been noted in the Census Report upon Irrigation, page 213, that the water supply of Malheur County is below the needs of the present population, and that in 1888 and 1889 there was great suffering among the farmers living along the lower part of the streams. In the upper valleys much of this water might be conserved by the erection of suitable dams.

Columbia River drainage in Washington.—The most important reservoir sites in this State, the waters from which are now needed, are those on the western side of the Cascade Range, at the head waters of Yakima River. The natural conditions are singularly favorable for storing waters in large volumes at relatively small cost, since there exist almost innumerable lakes and basins, some of which are of considerable size. The most notable are lakes Keechelus, Kachess, and Clealum, on the main Yakima River, and Bumping Lake, on Naches River. The

relative location of these lakes is shown in figure 165, page 462, of the Nineteenth Annual Report, Part IV.

Irrigation companies having lands in the valleys below have made surveys of these lakes and prepared estimates for private use, the figures not being made public. A detailed survey of Bumping Lake was, however, made by the Geological Survey in the summer of 1897. It was found that the area of this lake is 631 acres, while the area flooded by a dam raising water 25 feet will be 1,113 acres, giving a reservoir capacity of 22,300 acre-feet. The length of the dam should be 480 feet. (Nineteenth Ann. Rept., Pt. IV, p. 476.) The character of Bumping Lake is shown by figure 167, page 475, of the volume cited.

By the construction of reservoirs at these points waters can be turned into the head waters of the river during the season of drought, furnishing a supply for the irrigation of lands along Yakima and Naches rivers, and can be diverted into adjacent tributary valleys which, without these, can not be reclaimed. The location of the present ditches and the condition of development are shown in the Nineteenth Annual Report, Part IV, on pages 461 to 476.

Pacific drainage in California.—In California there are two systems of reservoirs whose need is most urgent—those within the high Sierras, on the head waters of streams flowing into San Joaquin Valley; and those in southern California, in the high mountains from which the Santa Ana, San Gabriel, and other rivers issue.

In the high Sierras reservoir surveys have been made as described in detail in the Thirteenth Annual Report, Part III, pages 398 to 405. Estimates for various types of dams are given, showing a range in cost under various conditions. For example, at Kennedys Meadow reservoir, on the head waters of Stanislaus River, the cost of an earthwork embankment is given as $46,000 and of a masonry dam of the same height as $128,000. The most pressing need of reservoirs, however, is probably on the head waters of Kings River. The relative position of the various reservoir sites surveyed is shown in the Eleventh Annual Report, Part II, on Pl. LXXXVI.

In southern California many surveys have been made by the State and by private parties, the detailed estimates obtained not being available for publication. Much of the country has been mapped by the topographers, and the area of the watersheds outlined, giving facts as to the probability of obtaining a supply of water for the reservoirs. The most important site is probably on or near the head waters of Santa Ana River, and the second in importance on San Gabriel River.

TABLE OF ESTIMATES.

The following table has been prepared for the hydrographic basins named above, giving in round numbers the approximate expenditures which may be incurred in the construction of these reservoirs. As before stated, it should be noted that final estimates, as a basis for actual construction, can be made only when certain questions as to funds available for the work have been settled. The estimates upon which this table is based range from those made in great detail from plans drawn to scale, and quotations of the cost of material, down to others which are of the nature of approximations.

Upper Missouri Basin, for benefit of Montana and North Dakota—Sun River system	$800,000
Upper Missouri Basin, for benefit of Wyoming; also Platte Basin, for benefit of Wyoming and Nebraska, including Sweetwater and Laramie system	900,000

Platte and Arkansas basins, for benefit of Colorado and Kansas, including South Platte reservoir, $500,000, and Arkansas River, $500,000	$1,000,000
Rio Grande, for benefit of Colorado and New Mexico, including Puerco and Pecos rivers	300,000
Colorado River drainage, for benefit of Arizona—Queen Creek reservoir	250,000
Salt Lake drainage, for benefit of Idaho and Utah—Bear Lake system	250,000
Columbia River drainage, for benefit of Idaho—Snake River system	250,000
Columbia River drainage, for benefit of Oregon—Wallawalla, Malheur, and Owyhee rivers	250,000
Columbia River drainage, for benefit of Washington—Yakima lakes	250,000
Interior Basin drainage, for benefit of Nevada—Donner Lake and Humboldt River	250,000
California drainage—Kings, San Gabriel, and Santa Ana rivers	500,000
Total	5,000,000